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Research Article

Italian Residential Buildings: Economic Assessments for Biomass Boilers Plants

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Biomass is increasingly used for energy generation since it represents a useful alternative to fossil fuel in order to face the pollutions and the global warming problem. It can be exploited for heating purposes and for supplying domestic hot water. The most common applications encompass wood and pellet boilers. The economic aspect is becoming an important issue in order to achieve the ambitious targets set by the European Directives on Renewable Sources. Thus, the present paper deals with the economic feasibility of biomass boiler plants with specific regard to an existing residential building. An Italian case study is further investigated, focusing the attention on European and national regulations on energy efficiency and considering the recent public incentives and supporting measures. The main thermoclimatic parameters—that is, heating degree days (HDDs), building thermal insulation and thermal needs—are taken into account. Moreover, the following economic indicators are calculated: cumulative cash flow, discounted cumulative cash flow, payback period (PP), net present value (NPV), Internal rate of return (IRR), discounted payback period (DPP), and profit index (PI).

1. Introduction

The problem of global warming, the growing pollutant emissions, and the increasing energy demand together with the reduction of fossil fuel sources have led many countries to consider and develop the Renewable Energy Sources sector and Europe to adopt some specific regulations on this matter [1, 2].

The European Directive 2009/28/EC—also well known as "Directive 20-20-20"—set many climate and energy targets in order to achieve and ensure a clean and sustainable living for the future generations: reduction of greenhouse gases emissions by 20%, energy production from renewable sources in percentage of 20%, and improvement of the energy efficiency by 20% in order to reduce the energy consumption [3, 4].

In this context, the biomass represents a good solution for RES developing since it is widespread in many different areas; indeed, it encompasses all organic matter of vegetable or animal origin. Biomass from plant is a product of photosynthesis process and can be considered carbon neutral since the amount of the released carbon, during its energetic conversion process, is similar to the quantity absorbed during its life time [5–7]. The cycle from biomass and fossil fuel to energy can be shortly represented as follows: biomass consumes CO_2 through photosynthesis, which is the process used by plants and other organisms to capture sun's energy, and the solar energy is stored in the chemical bonds of their structural components; when this energy is extracted, CO_2 becomes available to produce new biomass; the process is cyclical. Burning fossil fuels, old biomass (whose conversion took millions of years), is exploited, so that new CO_2 is generated through the combustion, increasing the greenhouse effect. In contrast, burning new biomass does not add new CO_2 since replanting new biomass permits carbon dioxide to be absorbed and returned cyclically [8]. For this reason, biomass can be seen as a neutral fuel: combustion produces the same amount of CO_2 which is absorbed during the whole life cycle of plants [9, 10]. Furthermore, during the biomass conversion into energy, low pollutants are emitted. Polycyclic Aromatic Hydrocarbons (PAHs) and CO_2 emissions can be reduced by simply varying some parameters of conversion technologies [11]; moreover, since biomass has low nitrogen and sulphur contents, low emissions of NO_x and SO_x occur [12, 13]. In addition, biomass has a small content of pollutants and ashes, despite the possible variations of some chemical components and moisture [14].

In order to convert biomass into energy, several categories of processes can be exploited depending on biomass characteristics, namely, thermochemical conversion, biochemical conversion, and mechanical extraction. Direct combustion, gasification, and pyrolysis belong to the first category [15, 16]. Combustion is the most widespread process, and it mainly exploits wood biomass; the most common and commercial application is represented by biomass boiler, using wood or pellet.

In the present work, an economic assessment of a biomass boiler installation in Italian residential buildings has been investigated using the main financial indicators: cumulative cash flow, discounted cumulative cash flow, payback period (PP), net present value (NPV), internal rate of return (IRR), discounted payback period (DPP), and profit index (PI).

A two-storey single building located in Viterbo has been considered. In the current condition, the building has a methane traditional boiler for heating and domestic hot water (DHW) supply. A study on the energy improvement has been carried out considering the replacement of the methane boiler with a biomass one. The DHW demand has been covered with a solar collector. The study has been carried out on two different cases concerning the thermal insulation of the building.

Case 1. A not well thermally insulated building, for which a replacement of the fixtures and an insulation cover for the external walls have been considered in order to lead it to Case 2 conditions; in the economical assessment, the thermal insulation costs have been taken into account.

Case 2. A thermally insulated building for which the thermal insulation costs are not to be considered.

The use of the biomass boiler and the solar collector permits us to gain access to the Italian Renewable Heat Incentive. In the following paragraph, a brief description of the European and Italian Regulations and the supporting measures are reported.

1.1. European Regulations and Italian Incentive Measures. Energy efficiency improvement in Italian buildings is an extremely important aspect to ensure energy saving and green-house gases (GHGs) emissions reduction. According to ENEA, most of the dwellings in our country were built before the first law on reducing building energy consumption (Legislative Decree 373/76) came into force. More than 2.7 million residential buildings, heterogeneously distributed in the whole territory and mostly belonging to the coldest climatic areas and having a low-thermal performance building envelope, are present in Italy. This is the reason why the residential sector is characterised by the highest energy consumptions corresponding to 36% (48 262 ktoe) of the national demands and whose mean value is equal to 150–200 kWh/(m^2× year). The thermal need represents 85% of the building energy demand, including space heating (70%) and domestic hot water (15%) (year 2007) [17, 18].

Table 1: Eligible projects included in category 1 (Legislative Decree 28th December 2012).

Project identification code	Eligible projects
1.A	Thermal insulation of opaque enclosures
1.B	Replacement of transparent enclosures
1.C	Replacement of existing winter heating systems with condensing heat generator
1.D	Shadowing and shielding systems for transparent enclosures

Hence, in order to speed up the transition from existing heating systems towards more efficient alternatives, in recent years, many incentive schemes have been adopted in Italy [19]. In more detail on 28th December 2012 the so-called "Renewable Energy for Heating and Cooling Support Scheme" has been established; it represents the Italian Supporting Measures and implements the previous Legislative Decree number 28 of 3rd March 2011. This policy strongly encourages the use of wood and pellet boilers [20]. Indeed, according to the European Directive 2009/28, public support is needed to reach the community's purposes on renewable energy sources (RES) use [21].

The Italian incentive mechanism carefully defines the supporting scheme for small-scale projects concerning energy efficiency improvements in existing buildings (called "category 1") and thermal energy production by the use of RES and high efficiency systems ("category 2"), as shown in Tables 1 and 2. The term "replacement" means the substitution of an existing power system with a new solution, whose capacity must not exceed more than 10% of the old system. If this constraint is not respected, the corresponding incentive will not be awarded [20].

According to the national regulation, two different parties are eligible, namely, public administrations and private parties. The first parties may apply for both categories, while private parties may require incentives only for category 2. Moreover, focusing the attention on new buildings or on those subject to major renovation, the supporting measure will cover only the part of the project exceeding the mandatory targets set by Legislative Decree number 28. The supporting measures will be granted only for those projects which do not benefit other incentives from the government [20].

In order to further improve the energy efficiency in new or existing buildings—both for thermal behaviour and heating/cooling systems—it is fundamental to analyse the thermal and electrical needs. This goal is successfully reached by carrying out the so-called Energy Performance Certificate (EPC) which was laid down by the European Directive 2002/91. With regards to the regulation, "energy performance of a building" is meant as the amount of energy actually consumed or estimated to meet the different needs associated with a standardised use of the building itself, which may

Table 2: Eligible projects included in category 2 (Legislative Decree 28th December 2012).

Project identification code	Eligible projects
2.A	Replacement of existing winter heating systems with heat pumps, whose thermal capacity must be less than 1000 kW
2.B	Replacement of existing heating or cooling systems for greenhouses or agricultural buildings with heat generators supplied by biomass, whose thermal capacity must be less than 1000 kW
2.C	Solar thermal collector, whose total area must not exceed 1000 m^2
2.D	Replacement of electrical boilers with heat pump boilers

include heating, hot water heating, cooling, ventilation, and lighting. When buildings are constructed, sold, or rented out, the EPC is made available to the owner or by the owner to the prospective buyer or tenant, as the case might be. The validity of the certificate should not exceed 10 years [22].

The above-mentioned regulation was repealed by the European Directive 2010/31 with effect from 1 February 2012. Since buildings account for 40% of total energy consumption in the Union and the sector is still expanding, member states should ensure that all new buildings occupied and owned by public authorities are nearly zero-energy buildings, by 31 December 2020 and 31 December 2018, respectively. In more detail, a "nearly zero-energy building" is referred to, a very high energy performance structure as determined in accordance with Annex I. A very limited amount of energy required should be covered—to a very significant extent—by energy from renewable sources, especially on-site or nearby [23].

The European Directive 2012/27 establishes a common framework of measures for promoting energy efficiency within the Union in order to ensure the achievement of the Union's 2020 20% headline target on energy efficiency and to pave the way for further energy efficiency improvements beyond that date [24].

With specific regard to Italy, the concepts of energy savings in buildings, rational utilisation of energy, and sustainable use of RES were introduced by the National Law 10/91 [25]. In recent years, the legislative framework has been further developed and is still changing in order to comply with the above-described European Directives. The following national regulations must be taken into account to carry out the Energy Performance Certificate.

(i) Legislative Decree 192/05 on energy efficiency of buildings [26].

(ii) Legislative Decree 311/06 which encompasses corrections and integrations to the Legislative Decree 192/05 [27].

(iii) Presidential Decree 59/09 which enforced Legislative Decree 192/05 [28].

(iv) National guidelines for energy performance set by the Ministerial Decree 26/06/2009 [29].

(v) Ministerial Decree 22/11/2012, including corrections and integrations to the Ministerial Decree 26/06/2009 [30].

In order to benefit the incentives laid down by the Renewable Energy for Heating and Cooling Support Scheme, the EPC must be carried out in case of replacement of existing winter heating systems with biomass boiler if the renovation is applied to the whole building, having a nominal power more than 100 kW.

2. Materials and Methods

The system considered in the present study consists of a single building located in Viterbo (Northern Latium, Central Italy). The structure is a 2-storey, rectangular-shaped building, with external gross dimensions of 6 m × 10 m. The total footprint area is 102 m^2, leading to a total heated volume of 275.4 m^3 since each floor is 2.7 m high. External walls are made of 28 cm of brick elements, without any insulation cover. Moreover, an internal and external layer of plaster—whose thickness is equal to 20 mm in both cases—is added. Table 3 shows the main thermal parameters of the current wall layers in the building. The roof and the ground floor consist of ordinary concrete structure. Windows are 1 or 2 double glass panes-solutions with wooden frame and are located in the eastern, southern, and western sides of the considered dwelling. The overall thermal transmittance of the transparent enclosures is equal to 2.8 W/(m^2× K). Windows account for 19.48 m^2, corresponding to 10% of the external wall surface. Space heating and domestic hot water (DHW) are supplied by means of a 24 kW methane-traditional heat generator, whose parameters are summarized in Table 4. The heat distribution system is ensured by traditional radiators. The building in this condition represents the studied Case 1 in the present paper.

Since the dwelling is represented by a residential building (belonging to category E1 according to the Presidential Decree 412/93), the set point for indoor temperature is assumed to be equal to 20°C to ensure thermal comfort [31].

Broadly speaking, the working period of the heating systems depends on climatic conditions and on the so-called heat degree days (HDDs). The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDDs at that location. HDDs are defined relative to a base temperature which is the outside temperature above which a building does not need heating. In order to evaluate HDD, an approximation method is used by taking the average temperature on any given day and subtracting it from the base temperature. If the value is

Table 3: Main thermal parameters for the current wall stratigraphy of the building (Case 1—*ante operam*).

Materials	Thickness (mm)	Thermal conductivity (W/m × K)	Density (kg/m^3)	Resistance factor (dimensionless)	Specific heat (J/kg × °C)	Thermal resistance (m^2 × K/W)	Overall thermal transmittance (W/m^2 × K)
Internal plaster	20	0.35	1200	10	835	0.057	
Brick	280	0.777	1800	15	835	0.36	1.642
External plaster	20	0.9	1800	20	835	0.022	

Table 4: Main parameters of the traditional heat generator (Case 1—*ante operam*).

Parameters	Values
Nominal power for heating (min/max)	11.0/24.6 kW
Nominal power for DHW (min/max)	11.0/24.6 kW
Useful power output (min/max)	9.6/22.9 kW
Temperature range for heating	82/40°C
Temperature range for DHW	60/36°C
Efficiency considering the nominal power	93.0%
Efficiency considering 30% of the nominal power	92.8%

Table 5: HDD, heating hours per day, and heating period (Decree 412/93).

Climatic area	HDD	Maximum heating hours per day	Heating period
A	<600	6	December 1–March 15
B	601–900	8	December 1–March 31
C	901–1400	10	November 15–March 31
D	1401–2100	12	November 1–April 15
E	2101–3000	14	October 15–April 15
F	>3000	No limitations	No limitations

less than or equal to zero, that day has zero HDD; if the value is positive, that number represents the number of HDDs on that day. Thus, only the positive differences of temperature must be considered. HDDs are calculated with (1) [32] as follows:

$$\mathrm{HDD} = \sum_{i=1}^{\mathrm{nhd}} \left(T_0 - T_i\right), \quad (1)$$

where i is value varying from 1 to the number of heating days (nhd), T_0 is the base temperature (°C), and T_i is the mean daily external temperature (°C). According to the value given by (1), Italy is divided into six different areas—from zone A (the hottest one) to zone F (the coldest one)—as shown in Table 5. More precisely, HDDs increase when the climate becomes colder. Viterbo belongs to zone D, having 1989 HDDs.

Considering all the input data mentioned in Tables 3, 4, and 5, the software DoCeT has been used in order to calculate the total primary energy consumption for space heating, DHW, and electrical purposes and, as a consequence, the energy class of the building. The obtained results are summarized in Table 6 [33].

Table 6: Output data generated by DoCeT for the residential building (Case 1—*ante operam*).

Output data	Case 1
Primary energy for space heating	299.5 kWh/m^2
Primary energy for DHW	21.8 kWh/m^2
Primary energy for electrical uses	4.1 kWh/m^2
Total primary energy consumption	325.4 kWh/m^2
Thermal need for space heating	204.9 kWh/m^2
Thermal need for DHW	17.1 kWh/m^2
Cooling need	18.6 kWh/m^2
Global energy class (space heating and DHW)	G
Partial energy class with regard to heating and cooling	G
Building envelope performance	II
Partial energy class with regard to DHW	E
CO_2 emissions	88.2 kg/m^2

In order to improve the energy and thermal performance of the building, the following actions can be carried out:

(i) insulation layer within the external wall;

(ii) supplying DHW demand by installing solar collectors on the roof;

(iii) providing space heating and DHW by means of a pellet boiler.

With specific regard to the first stage, Tables 7 and 8 show the main thermal parameters of the building in case of insulating the external wall and the improvements of the building envelope in terms of thermal behaviour. In order to access the 65% tax deduction regulation, the overall transmittance of the wall must not exceed the limit values reported in the Ministerial Decree 59/09, if the project is carried out in climatic areas belonging to classes C, D, E, and F [34].

The transparent enclosures may be replaced by double glass panes-solutions with PVC frame, whose overall thermal transmittance is given by 1.1 W/m^2× K.

An energy analysis has been carried out with DoCet software for the thermally insulated building too, considering a methane boiler for heating and DHW supply. The building in these conditions represents Case 2 studied in the present paper. The results are reported in Table 9.

For both Cases 1 and 2, the installation of solar collectors and pellet boiler has been evaluated in order to enhance the energy properties of the building.

TABLE 7: Main thermal parameters for the current wall stratigraphy of the building (Case 1—*post operam* and Case 2).

Materials	Thickness (mm)	Thermal conductivity (W/m × K)	Density (kg/m^3)	Resistance factor (dimensionless)	Specific heat (J/kg × °C)	Thermal resistance (m^2 × K/W)	Overall thermal transmittance (W/m^2 × K)
Internal plaster	20	0.35	1200	10	835	0.057	0.359
Brick	280	0.777	1800	15	835	0.36	
Insulating layer	50	0.023	38	89900	1392	2.174	
External plaster	20	0.9	1800	20	835	0.022	

TABLE 8: Overall transmittance of the building envelope (Case 1—*post operam* and Case 2).

Overall transmittance Case 1—*post operam* and Case 2 (W/m^2 × K)	Limit value according to Presidential Decree 59/2009	Overall transmittance Case 1—*ante operam* (W/m^2 × K)	Overall transmittance reduction (W/m^2 × K)
0.359	0.36	1.642	−1.283

TABLE 9: Output data generated by DoCeT software for the residential building (Case 2—*ante operam*).

Output data	Case 2
Primary energy for space heating	160 kWh/m^2
Primary energy for DHW	21.8 kWh/m^2
Primary energy for electrical uses	4.1 kWh/m^2
Total primary energy consumption	186 kWh/m^2
Thermal need for space heating	102 kWh/m^2
Thermal need for DHW	17.1 kWh/m^2
Cooling need	19.7 kWh/m^2
Global energy class (space heating and DHW)	F
Partial energy class with regard to heating and cooling	F
Building envelope performance	II
Partial energy class with regard to DHW	E
CO_2 emissions	37 kg/m^2

TABLE 10: Main characteristics of the biomass boiler.

Characteristics	Values
Fuel	Pellet
Rated power (P_n)	12 kW
Efficiency	93%
Consumption	0.9–2.75 kg/h
Heatable volume	315 m^3
Water buffer tank	600 L

The solar collectors to be located on the roof have been preliminarily designed assuming 4 occupants and 50 L/person as water demand. This leads us to calculate the collector surface (3 m^2) and the diameter of the pipe within the collector (16 mm). The tank volume is equal to 220 L.

As for the heating system, the chosen biomass boiler has the characteristics reported in Table 10 (according to UNI EN 303-5-2012 standard).

Considering all the above-mentioned input data and the results coming from the design procedures, the software DoCeT has leds us to calculate an approximate estimation

TABLE 11: Output data generated by DoCeT for the residential building (*post operam* both Cases 1 and 2).

Output data	Values
Primary energy for space heating	137.3 kWh/m^2
Primary energy for DHW	0 kWh/m^2
Primary energy for electrical uses	4.2 kWh/m^2
Total primary energy consumption	141.5 kWh/m^2
Thermal need for space heating	102 kWh/m^2
Thermal need for DHW	17.1 kWh/m^2
Cooling need	19.7 kWh/m^2
Global energy class (space heating and DHW)	E
Partial energy class with regard to heating and cooling	F
Building envelope performance	II
Partial energy class with regard to DHW	A
CO_2 emissions	0.3 kg/m^2

of the total primary energy consumption for space heating, DHW, and electrical purposes and, as a consequence, the energy class of the buildings in *post operam* conditions, as summarized in Table 11 [33].

The chosen solar collectors and biomass boiler fulfil the technical requirements set by the Renewable Energy for Heating and Cooling Support Scheme.

With specific regard to the cases described, the EPC is not needed. However, it has been carried out since it is fundamental to understand the current energy class of the dwelling and the future and possible improvements by modifying the building envelope and the energy supply plants [19]. As it is commonly known, the energy efficiency is given on a scale from A$^+$—the most efficient homes—to G—the most energy consuming one. According to the national regulations, the EPC can be successfully carried out using the software DoCeT in case of existing residential buildings whose total area does not exceed 3000 m^2 [26–31].

The biomass boiler fulfils the technical requirements set by the support scheme, such as the observance of class 5 of the EN 303-5 technical standard, the efficiency higher than

Table 12: Utilization coefficient h_r (Decree 28th December 2012).

Climatic zone	h_r (hours)
A	600
B	850
C	1100
D	1400
E	1700
F	1800

Table 13: Coefficient C_i (Decree 28th December 2012).

	<35 KW	35–500 kW	>500 kW
Biomass boilers	0.045 [€/kWh$_t$]	0.020 [€/kWh$_t$]	0.018 [€/kWh$_t$]

Table 14: C_e coefficient values depending on the primary particulate emissions (Decree 28th December 2012).

PPBT (mg/Nm^3)	C_e
20 < emissions ≤ 30	1
10 < emissions ≤ 20	1.2
emissions ≤ 10	1.5

Table 15: Yearly incentive calculation for biomass boiler.

Parameters	Values
$I_{a,\text{tot}}$	907.2 €/year
P_n	12 kW
h_r	1400 hours
C_i	0.045 €/kWh
C_e	1.2
PPBT	10 ÷ 20

87 + log(P_n), and the observance of the pellet characteristics according to classes A1 and A2 of EN 14961-2.

According to the Italian supporting measures, the incentive for biomass boilers has been calculated as follows [20]:

$$I_{a,\text{tot}} = P_n \times h_r \times C_i \times C_e, \quad (2)$$

where

$I_{a,\text{tot}}$ is the yearly awarded incentive (€/year),

P_n is thermal power of the plant (kW),

h_r is the utilization coefficient in hours (Table 12),

C_i is a coefficient depending on the thermal power of the plant (Table 13),

C_e is a coefficient depending on the particulate emissions (Table 14).

The primary particulate emissions can be determined by following the CEN/TS 15883 or EN 13284-1 standards and with a formula described in Decree 28th December 2012.

The parameters and the yearly incentive for the biomass boiler are reported in Table 15.

Table 16: Incentive calculation for solar collectors.

Parameters	Values
$I_{a,\text{tot}}$	510 €/year
C_i	170 €/m^2
S_l	3 m^2

The yearly incentive ($I_{a,\text{tot}}$) awarded for the installation of the solar collectors is reported in Table 16 and is defined by the following formula [20]:

$$I_{a,\text{tot}} = S_l \cdot C_i, \quad (3)$$

where S_l is the gross surface of the solar collectors (m^2) and C_i is a coefficient depending on the total surface of the system.

Thus, the total yearly incentive is 1 417.2 €/year, and it is dispensed in two years.

Furthermore, private parties might benefit of the supporting measures for the energy efficiency improvement in the existing residential buildings by accessing the so-called "65% tax deduction," laid down by the recent Legislative Decree number 63 of 6th June 2013. The latter awards incentives for those projects which will be carried out until 31st December 2012 or 30th June 2014 in case of block apartments and involving the building envelope (both opaque and transparent enclosures), the installation of solar collectors, or the replacement of existing heating generators by means of a condensing boiler [34]. Thus, the tax deduction on the thermal insulation of the building has been taken into account for the studied Case 1.

3. Results

All costs for the above-described installations are reported for both Cases 1 and 2 in Table 17.

The energy consumption costs before and after installing biomass boiler and solar collector are reported in Table 18 for both Cases 1 and 2.

The benefits of the investment are shown for both cases in Table 19.

All the above-listed costs and benefits are useful in order to calculate the main financial parameters.

The cash flows (CF_t^*) are obtained by adding all the costs ($C_{i,t}$) and all the profits ($P_{i,t}$) related to the generic tth year, as shown in (4) [3] as follows:

$$\text{CF}_t^* = \sum_i P_{i,t} - \sum_i C_{i,t}. \quad (4)$$

The discounted cash flows have been calculated by [3]

$$\text{CF}_t = \frac{\text{CF}_t^*}{(1+r)^t}, \quad (5)$$

where r represents the weighted average cost of capital (WACC). It refers to the index which defines the average expected return considering the assets of the plant's owner. The cumulative cash flow and the discounted cumulative cash flow are reported in Figures 1, 2, 3, and 4.

Table 17: Table of costs for studied Case 1 and Case 2.

References	Components	Costs	Total (€)	Operating maintenance (€)
Market research	Pellet boiler	2750 €	2750	100
Market research	Water buffer tank	1300 €	1300	6.5
Latium region price list 2012 CODES A.11.02.1.c1 A.11.02.1.c2	Thermal insulation for external walls (Polyiso)	40.16 €/m^2 (up to 2 cm) 2.83 €/m^2 (for additional cm)	8393	—
Latium region price list 2012 CODE E.1.17.4	Solar collector	516.46 €/m^2	1549.38	—
Market research	Water tank	1250 €	1250	7.74
Latium region price list 2012 CODE A.16.01.a-b-c-d	Transparent enclosures	380 €/m^2	702	—
Total costs Case 1			22645	127
Total costs Case 2			6850	127

Table 18: Costs for energy consumption (Case 1 and Case 2).

	Energy consumption before installing biomass boiler and solar collector		
	Consumption (kWh/year)	Cost of methane (€/kWh)	Total (€/year)
Case 1			
Heating + DHW	20899.8	0.093	2105.9
Case 2			
Heating + DHW	12148.2	0.093	1129.78
	Energy consumption after installing biomass boiler and solar collector		
	Consumption (kWh/year)	Pellet cost (€/kWh)	Total (€/year)
Heating + DHW	12148.2	0.058	704

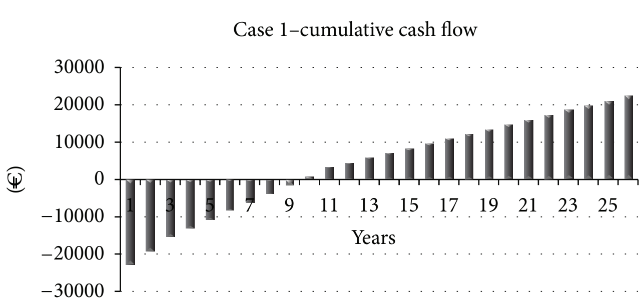

Figure 1: Trend of the cumulative cash flow for Case 1.

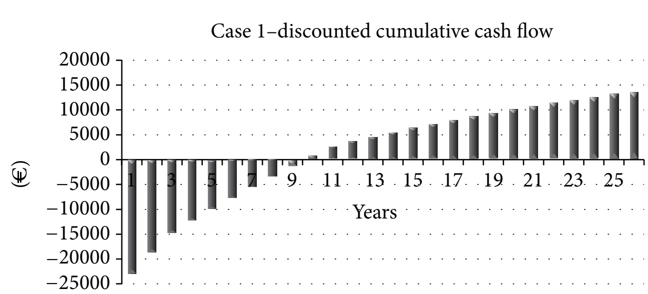

Figure 2: Trend of discounted cumulative cash flow for Case 1.

It can be easily seen that the payback period (PP) of the investment is 9 years for Case 1 and 13 for Case 2.

The net present value (NPV) has been evaluated using [3]

$$\text{NPV} = \sum_{t=1}^{N} \frac{\text{CF}_t{}^*}{(1+r)^t} - C_0 = \frac{P_1 - C_1}{(1+r)^1} + \cdots + \frac{P_N - C_N}{(1+r)^N} - C_0, \quad (6)$$

where N is the lifetime of the investment, considered equal to 20 years.

The discounted payback period (DPP) can be observed in Figures 5 and 6.

The internal rate of return (IRR) can be calculated through the following conditions:

$$\text{NPV} = \sum_{t=0}^{N} \frac{\text{CF}_t^*}{(1+\text{IRR})^t} = 0,$$
$$\text{PI} = \frac{\sum_{t=0}^{N} \left(P_t/(1+\text{IRR})^t\right)}{\sum_{t=0}^{N} \left(C_t/(1+\text{IRR})^t\right)} = 1. \quad (7)$$

The values of the IRR can be observed in Figures 7 and 8.

Table 19: Table of the benefits for studied Case 1 and Case 2.

Benefits	€/year	Period
Italian renewable heat incentive for biomass boiler	907.2	2 years
Italian renewable heat incentive for solar collector	510	2 years
65%-tax deduction—thermal insulation for external walls—Case 1	545.55	10 years
65%-tax deduction—transparent enclosures—Case 1	481.13	10 years
Annual cost saving for energy production—Case 2	425.2	
Annual cost saving for energy production—Case 1	1401.3	

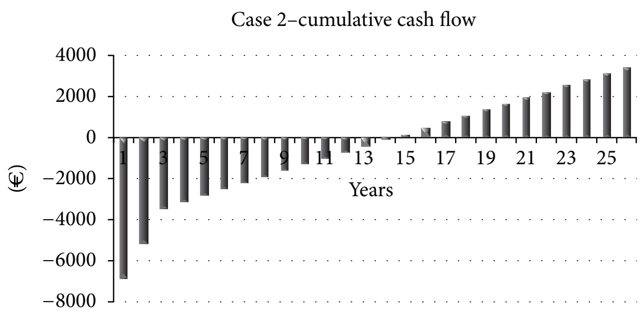

Figure 3: Trend of cumulative cash flow for Case 2.

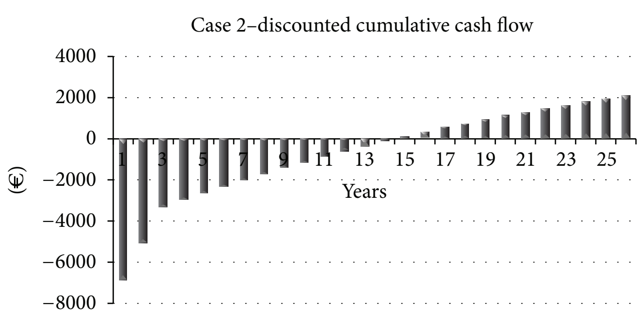

Figure 4: Trend of discounted cumulative cash flow for Case 2.

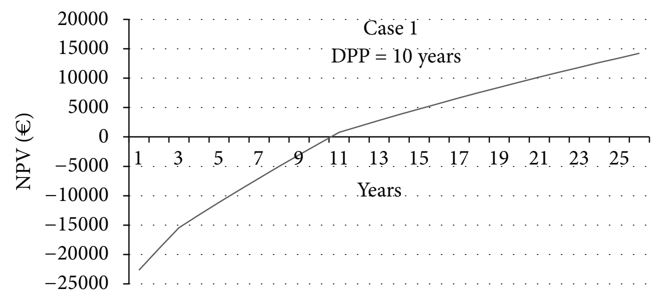

Figure 5: Trend of NPV depending on time for Case 1.

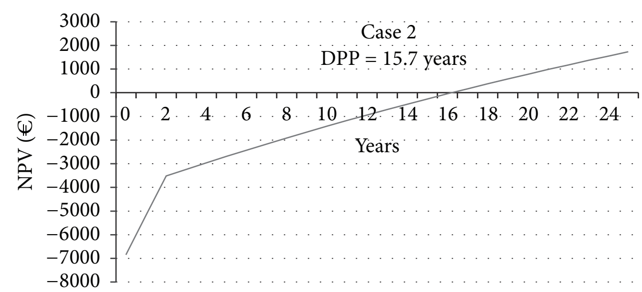

Figure 6: Trend of NPV depending on time for Case 2.

The profitably index has been calculated using the following:

$$\mathrm{PI} = \frac{\sum_{t=0}^{N}\left(P_t/(1+r)^t\right)}{\sum_{t=0}^{N}\left(C_t/(1+r)^t\right)} = \frac{P_0/(1+r)^0 + \cdots + P_N/(1+r)^N}{C_0/(1+r)^0 + \cdots + C_N/(1+r)^N}. \quad (8)$$

The main financial parameters are summarized in Table 20.

Table 20: Main financial indicators for both Case 1 and, Case 2.

Case 1	
Lifetime of the investment	20 years
PP	9 years
NPV	10170.11 €
DPP	10 years
IRR	7.5%
PI	1.41
Case 2	
Lifetime of the investment	20 years
PP	14 years
NPV	782.12 €
DPP	15.7 years
IRR	3.7%
PI	1.08

4. Conclusion

Two analyses have been carried out in order to assess the economical feasibility of biomass boiler plants in standard Italian residential buildings located in Viterbo. The first case studied concerns a not well thermally insulated building for which the following actions have been considered: energy efficiency improvement through insulation of the external walls and replacement of the transparent enclosures; installation of a solar collector to supply DHW; and installation of a pellet boiler to provide space heating and DHW if needed. The second case studied involves the same thermally insulated

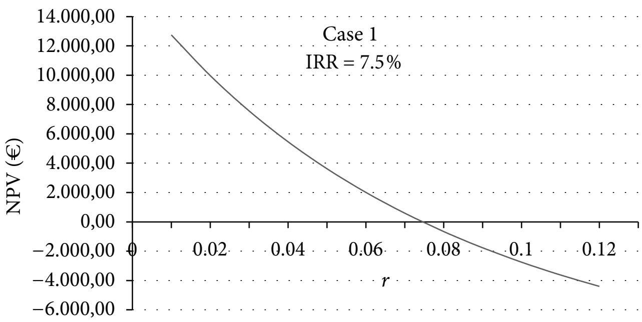

Figure 7: IRR for Case 1.

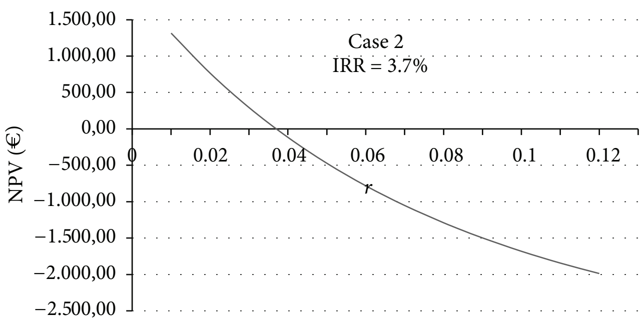

Figure 8: IRR for Case 2.

building for which the actions concern the solar collector and pellet boiler installations only.

All the installations fulfil the technical requirements set by the Italian Renewable Energy for Heating and Cooling Support scheme (Decree 28th December 2012) and 65% tax deduction (Legislative Decree no. 63 of 6th June 2013).

The supporting measures permit us to obtain good economic indicators for Case 1 which represents the condition with the highest investment costs. This is possible especially thanks to the 65% tax deduction and to the consumption reduction due to the energy efficiency improvement of the building.

In both studied cases, the major advantages are due to the energy and economic saving achieved with solar collector and pellet boiler installation compared to the use of the methane boiler.

However, the economic subsidy represents a fundamental tool for the payback period reduction and the dissemination of renewable energy sources for heating purposes and domestic hot water supply.

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